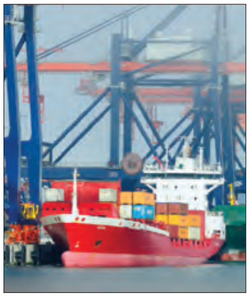


Chapter 8

Global Food Security, Climate Change, and the United States

Key Chapter Findings

- Many important connections that the United States maintains with the rest of the world, including trade, food and developmental assistance, and technological development, are essential for global food security and will be challenged by climate change.
- Climate change has the ability to disrupt food security by making it more difficult to get food from one region that is able to produce food to another region that wants to consume it, due to vulnerabilities in transportation infrastructure and related trade arrangements.
- The United States. will likely be directly and indirectly affected by changing global conditions and is expected to maintain strong food imports, exports, and assistance programs and be a source of innovative new technologies for addressing global food insecurity.

Achieving and maintaining global food security is in the best interest of the United States (CCGA 2013). According to the CCGA (2013), improvement in food security in low-income countries assists the United States in its humanitarian goals of helping improve quality of life, promotes global stability, and helps create future trading partners. To these ends, the United States makes significant contributions to global food security and provides key resilience to climate change through trade, assistance programs, technology transfer, and export of on-farm agribusiness management principles and management of off-farm waste streams and other indicators of sustainability.

Changes in food security are occurring globally and are expected to continue based on changes in climate conditions, food systems development, and external factors such as incomes (Smith et al. 2000). Because the global food system is highly integrated, the United States is not independent of these changes (Walthall et al. 2012).

Changes at the global scale are therefore likely to be reflected domestically, within the United States. This may be reflected in whom the United States exports to, what types of exports are in demand on the world market, the geographical origins and qualities of imported foods, the demands placed on assistance programs, changes in the domestic infrastructure necessary for moving food products, and considerations for the natural resource base within the United States in meeting these changing circumstances. These global influences occur even as climate change itself directly influences U.S. production patterns, agricultural management, and food-system structures, and as the world changes in important ways that are independent of climate change altogether. The potential for domestic change is therefore high, though the current state of scientific inquiry raises more questions than answers at this time.

This chapter explores the ways in which the United States relates to the global food system and how climate change modifies those linkages. It goes on to assess the means by which the changing global picture may feed back into the U.S. food system.

Changes in food security are occurring globally and are expected to continue based on changes in climate conditions, food systems development, and external factors such as incomes

8.1 The United States as a Global Food-System Actor

The U.S. food system operates within a global system of interconnected markets. It has become increasingly integrated in international trade as both a major exporter and importer of food (Walthall et al. 2012). In that regard, the U.S. food system has become highly responsive to the main drivers of change in global food demand, which are population and income growth (Alexandratos and Bruinsma 2012). Growth in global population, although historically large, is expected to slow in the coming decades, bringing with it a broader lowering of the growth rate of food consumption globally (Alexandratos and Bruinsma 2012). However, demand in many low-income countries, especially in sub-Saharan Africa where consumption rates are presently low, will continue to grow rapidly. Rising per-capita incomes in many low-income countries will decrease poverty and increase food consumption, although incomes will remain low enough in the lowest-income countries and subpopulations of other countries that significant food insecurity will persist (Alexandratos and Bruinsma 2012).

The role of U.S. food exports in the future is unclear. Alexandratos and Bruinsma (2012) anticipate more-vigorous international food trade in future decades, with more low- to middle-income countries becoming major food importers. However, they see several traditionally major exporting countries, such as the United States and Canada, conceding market share to rising exporter nations, such as the Russian Federation and Ukraine. For the United States, markets for exports will continue to grow, although the picture of future U.S. export growth is unclear as demand slows.

Three major challenges to achieving broader global food security (Godfray and Beddington et al. 2010) that are likely to involve the U.S. food system are: (1) closing yield gaps, (2) increasing production limits, and (3) reducing food waste.

8.1.1 Food Production

Increasing food production is a key to providing continued upward growth in food supplies at regional and international scales (Godfray and Beddington et al. 2010). Yield gaps are the difference between the realized crop productivity of a place and what is attainable using the best genetic material, technology, and management practices (Godfray and Beddington et al. 2010). The realized crop yields of some low-income countries are estimated to be approximately 60% of their potential (Godfray and Beddington et al. 2010). Ameliorating this gap with existing technologies and methods offers a significant opportunity to increase food production for the food insecure. Yield gaps are typically caused by lack of access to contemporary technology and management knowledge. Food-insecure nations can narrow yield gaps through effective technology transfer and management training (Godfray and Beddington et al. 2010).

Concern exists that many countries, including the United States, are divesting agricultural research focusing on increasing crop yields (World Bank 2008a). Very little of the total genetic material from original varieties is actually exploited in today's crops (Godfray and Beddington et al. 2010). Preserving heretofore unused genetic material is important to pushing yield limitations. International collections and gene banks are valuable repositories of genetic variation. The United States is a major repositor of landraces and other genetic material. The USDA's National Center for Genetic Resources Preservation (NCGRP; Williams 2005) is one of the world's largest collections of seeds, genetic material for livestock, microbes, and endangered plants. The mission of the NCGRP is to act as genetic and germplasm conservator into the future to protect the nation's and world's ability to develop new traits, especially those oriented toward increasing food supplies (Williams 2005).

Modern genetic techniques combined with a better understanding of crop physiology allow greater specificity in cultivating a suite of desired traits in crops and livestock (Godfray and Beddington et al. 2010). The first USDA-approved field releases of GM crops in the United States occurred in 1985, with four releases (Fernandez-Cornejo et al. 2014). By 2013, nearly 12,000 releases had been approved for corn, soybeans, cotton, and potatoes in the United States. Most of the companies producing GM crop seeds are U.S.-owned. Land planted with GM crops in the United States has rapidly eclipsed land planted with non-GM crops (Fernandez-Cornejo et al. 2014). Fernandez-Cornejo et al. (2014) found that consumers in many low-income countries were willing to pay more for certain GM crops over conventional counterparts, an inducement for producers in those countries to grow GM crops. This suggests that sales of GM seeds in many low-income nations could increase in the future, thus exporting technological advances that are needed to increase production limits in those nations. Cost, consumer demand, and other considerations, however, imply that the use of these particular technologies for adaptation in the food system to changes in climate is among the many choices facing decision makers in a changing climate (Azadi and Ho 2010, Scoones 2008, Masip et al. 2013).

8.1.2 Food Waste

Globally, 30%–50% of food is lost to waste (Gustavsson et al. 2011, Godfray and Beddington et al. 2010). Causes differ between high- and low-income countries. In low-income countries, the majority of waste occurs on-farm and in transporting and processing food. In high-income countries, most waste occurs in home consumption and very little is lost on-farm or in transportation and processing. Food waste at home by consumers in high-income nations primarily takes the form of discarding usable food because of qualitative deficiencies or failure to consume food within a certain period of time, regardless of its continued edibility.

Three global trends are posited to influence rates of waste in the food supply chain (Parfitt et al. 2010). The first trend is urbanization and the contraction of the agricultural sector. Nearly 50% of the world's population now lives in urbanized areas, and this number is expected to grow to 70% by 2050. This trend will lengthen food supply chains, which places food at increased risk of wastage due to added exposure during transportation, processing, and final consumption. The second trend is dietary transition. As incomes rise in many currently low-income countries, diets are changing. The food share of starchy staples declines as income increases (Parfitt et al. 2010). Higher incomes are accompanied by increased consumption of fresh fruit and vegetables, dairy, meat, and fish. Those foods tend to have shorter shelf lives and contribute to increased waste. The third trend is increased globalization of trade. International trade is leading to increased imports of high-quality foods that undercut domestically produced equivalents in many countries. Those imports are marketed in major supermarkets that dispose of large quantities of edible food for reasons of freshness and appearance.

The past seven decades have seen technological advances, such as improved genetics, fertilization, and mechanization, which have greatly increased total agricultural capacity and productivity in the United States. Many of those advances also helped increase the resilience of the U.S. food system to weather and climate extremes. For example, Tester and Langridge (2010) point out that recent transgenic crop modifications aimed at increasing yield stability have improved resistance to abiotic stresses such as drought. The advent of high-efficiency irrigation systems has improved water conservation, making more irrigation water available during droughts than was possible with lower-efficiency systems. Such technological advances, many of which are piloted in the United States, are likely to play a significant role in helping the nations across the globe deal with the consequences of climate change for food security for their citizens.

8.2 Climate and Weather Effects on U.S. Agriculture

The USDA sponsored an assessment report entitled "Climate Change and Agriculture in the United States: Effects and Adaptation," published in 2012 (Walthall et al. 2012). The information in this section is drawn from that recent work, unless otherwise cited.

As a large, mid-latitude nation with complex topography, the United States has widely varying climate conditions, ranging from very high precipitation coupled with very cool average temperatures (due to very long and cold winters) in Alaska to high precipitation and warmer average temperatures throughout the year in Florida. The Southwest has warm summers with low annual precipitation, whereas the Northeast has warm summers with high annual precipitation.

All regions of the United States have experienced climate change during the last century. Alaska has changed the most, with average temperatures increasing by 1–2 °C. Average temperatures have also increased in the northern Midwest, and the Southwest has also become warmer. The only region in the United States that cooled over the last century is the Southeast, although it has also experienced temperature increases during the last several decades. In most regions, summer has warmed more than winter, and spring is also warmer in most places (Walthall et al. 2012). In the United States, as in most other parts of the globe, the observed number of record highs during each year is now about three times the number of record lows (Meehl et al. 2009). Much of the Northwest, Central, and Southern United States now receive more precipitation than 100 years ago, while parts of the Eastern Seaboard, the Rocky Mountains, and the Southwest receive less. The intensity of precipitation has also increased in most areas of the United States. Increases in precipitation totals and intensity do not necessarily mean that additional water is available for agriculture. More intense rain leads to faster runoff, and higher temperatures increase evapotranspiration losses to the atmosphere, both of which result in less moisture retention in soils.

The entire United States is projected to warm substantially in the future. Even under a scenario of limited emissions increases and GHG concentrations (e.g., RCP 2.6), average temperatures are likely to increase by 1–2 °C over the next 40 years, which is substantially faster than the rate observed over the last 100 years (Figure 8.1). Temperatures would then remain at about this level throughout the rest of the century. If emissions follow a higher scenario (e.g., RCP 8.5), average U.S. temperatures could increase by 2–3 °C by mid-century. Looking ahead to 2100, a high-emissions scenario results in warming of 4–5 °C in most regions and 5–7 °C in parts of the interior West and Midwest. This widespread warming could increase the length of the growing season by a month or more and lead to 20–40 fewer frost days per year in most areas.

The picture of future precipitation shows more geographic variation (Figure 8.2). Over the next 40 years under a low-emissions scenario, most of the United States is projected to see increased average precipitation with some notable exceptions. Increases are greatest in the East. Only parts of the Southwest and the Pacific coast are projected to become drier. If emissions remain on a low trajectory, these conditions do not change significantly by 2100, except for a switch from drying to slightly increased precipitation in some parts of the Southwest. Under a high-emissions scenario, the pattern of change is similar in the near term but with larger increases in precipitation in much of the eastern United States and larger decreases over a slightly larger area of the Southwest. Over the longer term, there is a further increase in precipitation in more of the eastern United States, with the exception of Florida, which is projected to see decreased precipitation.

The changes in precipitation and temperature outlined above are extremely likely to have direct effects on U.S. agricultural production. Crops and livestock are sensitive to direct effects of climate changes, such as changing temperatures and precipitation. Exceeding optimum temperatures for crops steadily reduces productivity up to a threshold, after which productivity decreases sharply, and increases animal stress, especially when coupled with high humidity. Precipitation decreases can make it difficult to store and deliver adequate water to crops at the right time, while increased overall precipitation, and particularly increased intense precipitation, requires improved drainage to avoid crop and soil damage.

Agriculture is also sensitive to indirect effects, such as increases in diseases and pests, and degradation of the natural-resource base, such as high quality soil and water, upon which agriculture depends. Climate change is projected to increase the growth and range of many weeds, insect pests, and pathogens

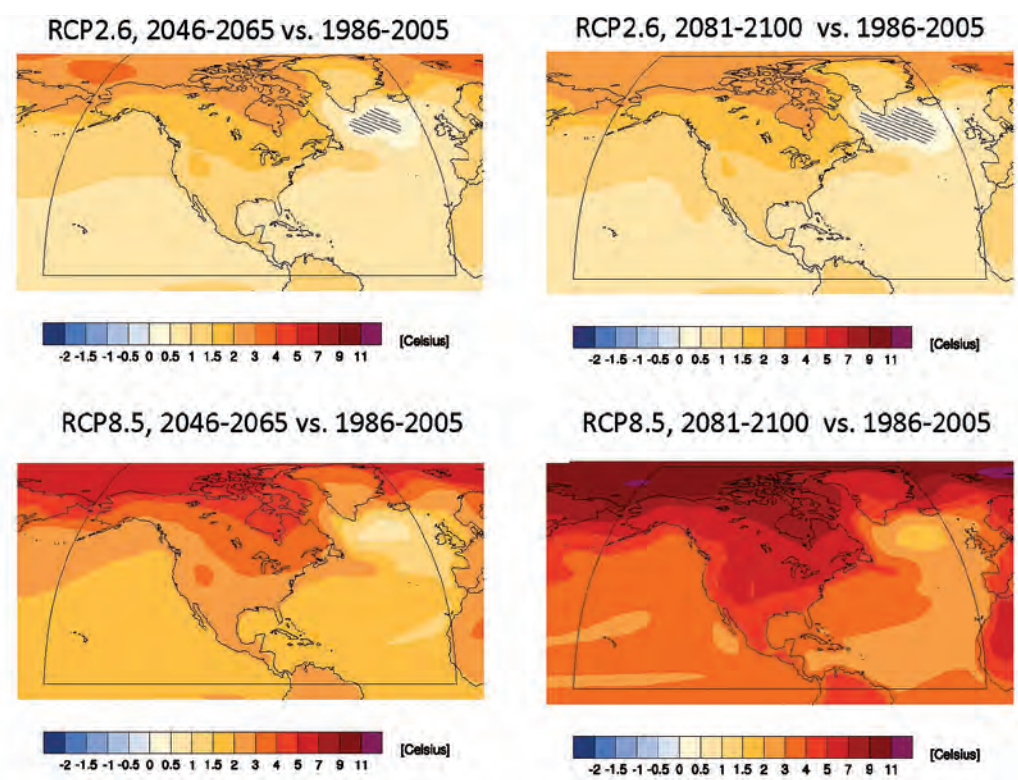


Figure 8.1 Projections of U.S. surface temperatures. *U.S. average surface temperature projections for the low-future-GHG-concentration scenario (upper panels) for mid-century (left panel) and end of century (right panel). Lower panels show projections based on high GHG concentrations for mid-century (left) and end of century (right). Plots show multimodel ensemble means, with gray dashes indicating areas where changes are small (less than one standard deviation) compared to natural variability. Source: This figure was produced using CMIP5 model output through the web application "Climate Explorer," available at http://climexp.knmi.nl/.*

harmful to agriculture, although the ranges of some invasive weeds could decrease. Projected increases of intense precipitation coupled with increased drying of soils from higher temperatures increases the risk of accelerated erosion of soils in many areas, which both degrades soil quality and increases the runoff of agricultural chemicals. Projected changes in precipitation are also likely to increase water-management challenges in agriculture. For example, the combination of decreased snowfall and snowpack, increased rainfall (from less precipitation falling in frozen form and more in liquid form), earlier snowmelt, and decreased summer flows in streams and rivers could increase the need for water storage in many areas of the western United States.

Overall, the U.S. food system is expected to be fairly resilient in the near term due to its capacity to undertake adaptive actions such as increased irrigation, shifting of crop rotations and acreage devoted to specific crops in some regions, and alteration of nutrient inputs and other management practices. As climate change continues and temperature increases of 1–3 °C are coupled with changes in precipitation timing and intensity, yields and farm returns are projected to decline. The continued changes expected between 2050 and 2100 under high-emissions scenarios are expected to have overall detrimental effects on most crops and livestock. Finally, it should be recognized that there is a significant chance that current projections underestimate potential declines, because most analyses exclude production constraints arising from increased pest pressures, extreme events, and decreased ecosystems services (Walthall et al. 2012).

8.3 The U.S. Role in a World Adapting to Climate Change

Climate change will occur at a pace and magnitude that will require adaptation (Porter et al. 2014). As part of the global food system, the United States is expected to participate in actions to adapt to climate change domestically and abroad. Four key areas in which the United States can be expected to play a role in adapting food systems to climate change abroad are (1) international trade, (2) food assistance, (3) development assistance, and (4) technology and information assistance. These are discussed below.

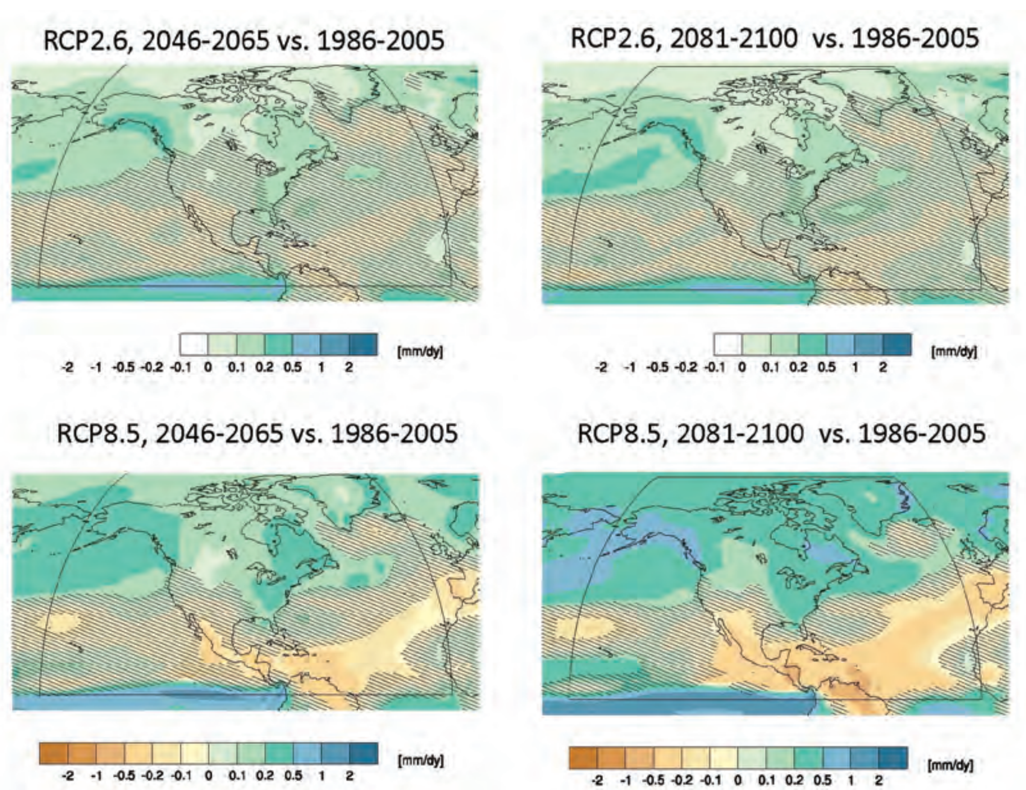


Figure 8.2 Projections of changes in U.S. precipitation. *U.S. precipitation changes for the low-future-GHG-concentration scenario (upper panels) for mid-century (left panel) and end of century (right panel). Lower panels show changes based on high GHG concentrations for mid-century (left) and end of century (right). Plots show multimodel ensemble means, with gray dashes indicating areas where changes are small (less than one standard deviation) compared to natural variability. Source: This figure was produced using CMIP5 model output through the web application "Climate Explorer," available at http://climexp.knmi.nl/.*

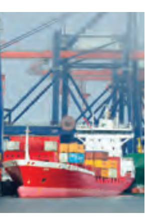
8.3.1 Trade

Information in this section is drawn from Walthall et al. (2012) unless otherwise cited.

International trade connects areas of resource surplus and deficit, lowers demand for land resources on a global level (Qiang et al. 2013), and stabilizes food availability and prices, to the benefit of many food producers and consumers (CCGA 2013). The United States contains 11% of the world's arable land, one of the highest endowments of any country (FAOSTAT 2014c). The United States produces about one-fifth of the world's grain and soybeans, and roughly one-sixth of the world's beef, pork, and poultry (USDA 2015).

An estimated 20% of U.S. agricultural production (based on volume) is exported (USDA ERS 2012), making the United States the largest food exporter in the world, responsible for 16% of global agricultural exports (GTIS 2015). The United States is the largest producer of corn in the world, responsible for over one-third of the world's corn crop, which is grown on over 400,000 U.S. farms (U.S. EPA 2013). More than 275,000 farms in the United States produce soybeans, making the United States the largest producer of that commodity as well (U.S. EPA 2013). The United States is also among the world's top wheat and rice suppliers and is responsible for one-quarter of the world's meat exports (USDA 2015).

Top markets for U.S. agricultural products include China, Canada, Mexico, Japan, and the European Union (USDA ERS 2014a). China is one of the fastest-growing agricultural markets, driven primarily by its burgeoning demand for soybeans and limited arable land base. Since international trade can contribute to global land savings if trade flows from a relatively efficient country to a less efficient country, it is estimated that China's import of land-intensive crops led to a global land savings of 3.27 million ha annually, on average, during 1986–2009 (Qiang et al. 2013). The United States' comparative advantage in land has enabled it to be the largest agricultural supplier to China, thus contributing to global land savings. In terms of global crop trade, the United States, Canada, Australia, and Argentina are net virtual land exporters, while some Asian and Mediterranean countries are net importers (Qiang et al. 2013, Fader et al. 2013).



Mirroring China's rise in market size, import demand for food and other agricultural products is generally expanding faster in developing countries than developed, reflecting more dynamic population and economic growth. Developing countries (defined by FAO to include all countries in Africa except South Africa, all countries in Asia except Israel and Japan, all countries in Oceania except Australia and New Zealand, and all countries in the Western Hemisphere except Canada and the United States) are expected to become more dependent on imports to meet their increasing demand, which is outstripping production (FAO 2002b). In 2014 about two-thirds of U.S. agricultural exports went to developing countries, compared with 48% in 1994 (USDA FAS 2015b). Demand growth in developing countries is expected to create additional opportunities for U.S. agricultural exports, although the United States will continue to compete with other major exporting countries (USDA 2014).

U.S. production affects global food security by influencing global commodity prices. In the summer of 2012, for example, a severe drought affected 80% of cropland in the U.S. Midwest (USDA ERS 2013b). Largely as a result of the diminished U.S. corn and soybean crop production, international prices for these commodities increased by 25% and 17%, respectively (World Bank 2012a). The influence of U.S. exports makes world food commodity prices dependent on weather and other supply-and-demand effects within the United States (USDA ERS 2015a). Weather and climate events in the United States also affect planting decisions in other countries. Farmers in Brazil and Argentina—both large corn and soybean exporters—react to prevailing U.S. prices and plant their crops accordingly (USDA ERS 2015a).

A significant aspect of U.S. agricultural trade with respect to climate change is the ability of the United States to export virtual water in the commodities being traded. Virtual water refers to the water that is embodied throughout the entire production process of a traded commodity (Hoekstra and Chapagain 2008). Many regions of the world where the risk of food insecurity is high are likely to simultaneously experience severe climate changes in the form of diminished precipitation and drought, including especially the tropics and semiarid tropics (Porter et al. 2014). Water will be a key limiting factor for food production in those areas. Konar et al. (2013) estimate that by 2030, if climate change causes moderate crop yield decreases globally, the United States would lead the world by a large margin in the amount of virtual water embedded in exported commodity crops. It is worth noting that only minimal global yield decreases are likely by 2030 (Porter et al. 2014). However, it can be inferred from the Konar et al. (2012) estimates that as global yield decreases become moderate later in the century, the

United States might maintain or even strengthen its role as a major exporter of food, especially commodities that require water (for production, processing, or transporting). Yet it is important to recognize that agriculture in some parts of the United States, particularly the arid West, may be as constrained by reduced precipitation and increasing demands on nonagricultural uses of water as other parts of the world (Walthall et al. 2012).

Trade is beneficial to the U.S. domestic economy. It is estimated that each dollar of U.S. farm exports stimulates an additional USD 1.22 in U.S. economic output (USDA ERS 2015b). Agricultural exports create additional economic output due to their effect on other nonagricultural industries. Farmers purchase additional machinery, durable goods, or other inputs to produce the exportable agricultural commodities. These purchases generate jobs, income, and wages for other sectors of the U.S. economy. In 2013, the most recent year for which trade-impact analysis is available, the USD 144.38 billion U.S. farm exports supported almost 1.1 million jobs, three-quarters of which were in nonfarm sectors (USDA ERS 2015b). In addition to direct, on-farm employment, agricultural exports also support economic off-farm activities associated with procuring production inputs such as fertilizers and fuel, processing, packaging, manufacturing, transporting, and financing and logistics activities. Similarly, agricultural imports generate economic output through transporting and retailing food (Paggi et al. 2012), though the multiplier effects are more difficult to quantify (USDA ERS 2015b).

U.S. imports play an indirect role in global food security. The United States is the third-largest food importer in the world; it imported USD 112 billion of agricultural products in 2014, including coffee beans, cocoa, fresh fruit, and rubber, as well as an additional USD 20 billion of fishery products (USDA FAS 2015b). The United States is the world's largest importer of edible seafood products, with an edible seafood trade deficit of approximately USD 15 billion in 2014 (NOAA Fisheries 2014). Imports generate income for overseas producers through export sales of surplus production, and, in some cases become the main source of income for farmers who have limited options. For instance, the United States is the largest importer of Guatemalan coffee, buying about 40% of the country's exported coffee beans (GTIS 2015). Coffee production supports 150,000 full-time and 300,000 part-time jobs in Guatemala, contributing 1.5% of that country's total GDP (USDA FAS 2015c). About 70% of the coffee production there is concentrated at high altitudes, where few alternative agricultural options are available. For a discussion on the importance of coffee to the Central American economy, the region's food security, and how climate change affects both, see Box 8.1. U.S. food imports from all regions are growing to meet consumer demand for variety, quality, and convenience (USDA ERS 2015a). Retailers and processors also seek low-cost ingredients sourced from all over the world, raising concerns about the safety of supplies from far-flung locations that have different safety standards and quality control (Gale and Buzby 2009). Food import refusal reports indicate that vegetables and vegetable products, fishery and seafood products, and fruits and fruit products are among the top imported food categories refused due to safety and other violations under FDA law, which includes sanitary, pesticide, labeling, and packaging violations (Buzby et al. 2008). Improved safety in imported food is likely to entail higher costs, as exporting countries invest in sanitary facilities, equipment, water treatment, worker hygiene, changes in production processes, and third-party certification (Gale and Buzby 2009).

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The AgMIP projections described in Chapters 3 and 4 of this volume can also be used to describe some possible climate change effects on food production in the United States. With the exception of domestic U.S. food prices, the effects of varying climate scenarios on U.S. imports and exports can be studied using AgMIP data. Within the models, the United States is classified as a region, and the effects of climate change can be assessed specifically for the United States (Valin et al. 2014). Several results from these projections provide additional information on the domestic climate change effects; changes in domestic U.S. food prices are not possible to glean from these models, however. The models use global commodity prices to determine when supply equals demand, which then calculate prices and other outputs for future commodities. Therefore, prices in the United States are the same as those observed in other regions of the world, except for costs associated with transportation, tariffs, and other trade-related price adjustments.

Table 8.1 provides information from the publicly available AgMIP data for U.S. imports and exports (Valin et al. 2014, Nelson and Valin et al. 2014). The table reports the average results of six different economic models to more clearly illustrate the effects of changes in agricultural imports and exports under different climate scenarios. The baseline scenario maintains the 2005 climate, while the alternative scenario is the average change based on four similar climate scenarios, all of which use emissions and

Box 8.1
Central American Coffee, the United States, and Climate Change—A Case Study

U.S. food imports provide an income source to exporting countries and can be important to the production choices, economic condition, and food security of those nations. High-value crops such as tropical fruits (e.g., bananas, pineapple) and coffee are examples. Coffee has recently demonstrated a sensitivity to changes in climate in Central America, the consequence of increasing temperatures and large production losses brought about by infestation of the fungal *Hemileia vastatrix* pathogen (coffee rust or *la roya*; Avelino et al. 2015).


Coffee leaf rust, Hemileia vastarix. (Smartse/Wikipedia Commons.)

Coffee was the eighth most traded agricultural commodity in the world in 2011 (FAOSTAT 2015b) and is important to many developing tropical economies. Global Exchange, a human rights organization, estimates that about 25 million people in 50 countries around the world currently depend upon the cultivation of coffee for their livelihoods (Global Exchange 2015), disproportionately represented by rural households.

The United States purchases over 40% of Central America's exported coffee, and as such, represents its primary market (USDA FAS 2015a). Imports from the combined countries of Central America (Guatemala, Costa Rica, Nicaragua, Honduras, El Salvador, and Panama—USD 1.05 billion) are approximately equivalent to those from Brazil (USD 1.1 billion), the largest individual source country of U.S. coffee (USTR 2015). Coffee is among the top three agricultural exports from each Central American country; the relative importance of agriculture to each economy and the domestic employment rate is listed in table below.

Changes in climate may have severe long-term effects for those who depend on coffee production. Arabica coffee, the most common variety, grows only in narrow climate conditions that require relatively constant temperatures and substantial rainfall. These conditions have existed in the mountainous regions of Central America, though climate projections suggest that farmers will be unable to continue to cultivate coffee in the same locations. In the short term, farmers may grow coffee at higher altitudes, tracking changing temperatures. Over the longer term, much of the suitable habitat in the region is expected to be lost entirely (Vermeulen et al. 2013).

Climate factors have been important drivers of the Central American *H. vastatrix* infestation. Temperature (a decrease in the diurnal thermal amplitude; Avelino et al. 2015), the seasonality of precipitation (Avelino et al. 2015), and higher humidity levels (Helfer 2013), consistent with anticipated changes in climate, are each implicated. Plants at higher altitudes were more vulnerable than in the past due to higher minimum daily temperatures (Avelino et al. 2015). Many operations may have been simultaneously more vulnerable to infection due to lower management investments, the result of low coffee prices on the world market, and the affordability of fertilizer and fungicides (Avelino et al. 2015).

Country	Coffee Exports to the U.S. (USD Million) (2013)	Agriculture Value Added (% of GDP) (2012)	Employment in Agriculture (% of Total Employment) (2012)
Costa Rica	204	6	13
El Salvador	91	12	21
Guatemala	420	11	32
Honduras	159	15	35
Nicaragua	165	18	32
Panama	7	3	17

Sources: Coffee Exports to the U.S. – USTR 2015; Agriculture Value Added – World Databank 2015a; Employment in Agriculture – World Databank 2015b.

(Box 8.1 continued)

The long time period required for coffee shrub establishment makes shifting plantations difficult, even in cases where land purchases are possible. Even in the shorter term, the effects on farmers are significant. Lost sales income is difficult to recover and damaging to farmers' food security (Avelino et al. 2015). Because of the high degree of economic dependence upon coffee cultivation in the region, lower production levels have affected the livelihoods of thousands of Central American smallholders and harvesters (Avelino et al. 2015). The Inter-American Institute for Cooperation on Agriculture estimates that over 17% of the region's agricultural employees were displaced in 2012–2013 as a consequence of coffee rust (IICA 2013). In 2013, the World Food Programme supplied emergency food assistance to more than 53,000 families in Guatemala, Honduras, and El Salvador due to food insecurity brought about by coffee rust (WFP 2013b).

Record production levels anticipated for Honduras in 2015 reflect more recent plantings with rust-resistant varieties (USDA FAS 2015a). There are multiple adaptation possibilities for managing *H. vastatrix*, including agronomic practices (Avelino et al. 2011, Lasco et al. 2014), biological controls (Haddad et al. 2009), chemical applications (Belan et al. 2015), and genetic breeding (Rozo et al. 2012, Silva et al. 2006), as well as monitoring and alert systems to acquire and disseminate actionable information (e.g., FEWS NET et al. 2014, SATCAFE 2015). Some adaptations may be quickly implemented; others may take decades to develop. Many will depend upon producers having the means of acquiring production inputs, new information, or technologies—means that have been measurably diminished by these events.

The example of Central American coffee production highlights several important concepts embodied within this report: the influence of trade on a nation's food systems and production choices; the importance of global production to the U.S. food supply; and the relevance of climate—present and future—for strategic management at all levels, from individual producers through the integrated global food system.

concentrations from RCP 8.5. The AgMIP data use 2005 as a base year, and for this table agricultural imports and exports are normalized to their 2005 values. Under both the baseline and climate scenarios, global population is expected to reach 9.3 billion people in 2050 and global GDP is expected to exceed USD 147 trillion (Valin et al. 2014). Over time, the table shows large increases in imports and exports for both scenarios. By 2050, agricultural imports to the United States are projected to increase by 67% under the baseline scenario (relative to 2005). Under a scenario that includes climate change, imports into the United States would increase by almost 73% relative to 2005. Similarly, exports are also expected to increase substantially, by 85% in 2050 under the baseline scenario and by 91% under a scenario that includes climate change.

While agricultural imports and exports are expected to increase over time, regardless of climate change, Table 8.2 shows the changes in agricultural imports and exports from climate scenarios expected relative to the baseline scenario in 2030 and 2050. Agricultural imports increase in a world with climate change relative to the baseline scenario. In 2030, the average increase in imports is almost 5% above agricultural imports relative to a world where climate is held constant at 2005 levels (the

Table 8.1 U.S. Agricultural Imports and Exports (AgMIP Projections). *AgMIP projections show increases in U.S. imports and exports in the years 2030 and 2050. Units are multiples of the 2005 baseline import and export volume. The climate scenario results are the average of six economic models over four different climate scenarios. The climate scenarios are generated from all possible pairings of two crop models and two general circulation models, and all use RCP 8.5. Source: Adapted from Nelson and Valin et al. 2014.*

	% Change in Imports Relative to 2005		% Change in Exports Relative to 2005	
Year	Baseline (No Climate Change)	Climate Scenario Average	Baseline (No Climate Change)	Climate Scenario Average
2005	---	---	---	---
2030	31.42%	37.18%	62.74%	65.61%
2050	66.75%	72.64%	85.24%	91.13%

Table 8.2 Change in U.S. Agricultural Imports and Exports Relative to Constant 2005 Climate. *When only climate change influences are considered, U.S. imports and exports are both expected to increase in the years 2030 and 2050. Units are percentage changes relative to the import and export volumes in 2030 and 2050 in a world where climate is held constant at 2005 levels. The climate scenario results are the average of six economic models over four different climate scenarios. The climate scenarios are generated from all possible pairings of two crop models and two general circulation models, and all use RCP 8.5. Source: Derived from Valin et al. 2014.*

	Imports		Exports	
Year	Baseline (No Climate Change)	Climate Scenario Average	Baseline (No Climate Change)	Climate Scenario Average
2030	---	4.38%	---	1.77%
2050	---	3.53%	---	3.18%

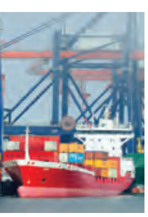
baseline). Agricultural exports also increase, with slightly smaller increases in exports relative to the baseline scenario. The U.S. agricultural balance of trade would therefore be expected to change based on these projections by 2050, with imports increasing slightly more relative to exports under the climate change scenario.

While the AgMIP results continue to show an increase in U.S. agricultural trade, the models do not account for potential vulnerability in transportation infrastructure. To be able to export and import goods, infrastructure such as ports and roads are necessary. AgMIP results focus on economic growth, population growth, and trade and are unable to model changes in infrastructure. Other studies demonstrate that it is a valid concern and influences whether U.S. and global infrastructure will be resilient to a changing climate (Nicholls et al. 2008). Therefore, it is important to discuss current major agricultural trading partners

Table 8.3 Top 15 Countries for U.S. Agricultural Exports

Rank	Country (Region)	Value (U.S. Dollars)
1	China	25,880,644,237
2	Canada	21,326,516,722
3	Mexico	18,098,808,744
4	Japan	12,138,761,149
5	European Union-28	11,857,780,593
6	South Korea	5,135,962,712
7	Hong Kong	3,852,064,120
8	Taiwan	3,088,863,591
9	Indonesia	2,823,768,279
10	Philippines	2,509,046,614
11	Turkey	2,148,734,476
12	Vietnam	2,128,330,507
13	Brazil	1,906,663,898
14	Egypt	1,651,981,562
15	Venezuela	1,545,396,029

Source: USDA ERS 2014a.



with the United States and port infrastructure to get food into and out of the country.

Major destinations for U.S. agricultural exports are presented in Table 8.3. Currently, the second- and third-largest U.S. trading partners are Canada and Mexico, which have common borders with the United States. However, the remaining major agricultural trading partners are distributed around the world, with the majority located in Asia, Europe, and South America. For the United States to exchange goods with trading partners, there must be adequate infrastructure in both the United States and its trading partners and that goods be exchanged in a timely manner to prevent food waste as well as the excessive costs associated with perishable goods storage.

In assessing the vulnerability to climate change, one report estimates that three of the largest U.S. ports (by volume) are at significant risk (Nicholls et al. 2008). As major export and import hubs, this vulnerability could directly affect the agricultural export capabilities of U.S. farmers and limit the ability of the United States to receive food imports. Table 8.4 lists the international ports most vulnerable to sea level rise; many are in countries that are major importers of U.S. agricultural products. Therefore, climate change has the ability to disrupt food security simply by making it more difficult to get food from one region that is able to produce the food to another region that wants to consume that food.

8.3.2 U.S. Foreign Assistance

In addition to helping countries meet agricultural development and long-term food-security objectives, U.S. foreign assistance, including both development and international food assistance, is an important instrument for meeting the needs of vulnerable populations, including those experiencing food shortages brought on by drought and other climate-related factors (Rosen et al. 2014). Food assistance will likely continue to be a major tool for ameliorating food insecurity in the early stages of climate change, when many low-income nations are just beginning to experience rising incomes (Barrett and Maxwell 2005). Increasing emphasis is being placed on building resilience to recurrent crises in order to reduce the need for humanitarian assistance over the longer term (see, for example, Executive Order 13677 2014). Both emergency food assistance and longer-term development programs are important to building more-resilient, food-secure communities. The consequences of climate change for food security in different regions globally likely will influence, and be influenced by, development efforts.

In a changing climate, the multiple actors driving engagement between the U.S. food system and global food security include the U.S. government; U.S. civil society, including nonprofit organizations, philanthropic foundations, voluntary organizations, faith-based groups, and academic institutions; and private-sector actors, including large corporations and small businesses.

U.S. government international food-security programs analyze climate risks and aim toward climate-resilient outcomes (Executive Order 13677 2014). Global food security also represents a strategic priority for the United States, as food insecurity in weakly governed areas is considered to be a potential national security threat (Clapper 2014). International food assistance is provided by USAID's Office of Food for Peace and USDA's Foreign Agricultural Service (FAS). FAS administers two food-assistance programs with agricultural-development and long-term food-security objectives: the McGovern-Dole International Food for Education and Child Nutrition program and the Food for Progress program. Food for Peace, administered by USAID, provides flexible emergency programming through interventions such as local and regional procurement and cash transfers and food vouchers to optimize response time during emergencies, as well as *in-kind* food from the United States. Each is described in greater detail in this section.

Table 8.4 Top 20 Port Cities With Severe Potential Impacts From Sea-Level Rise and Tropical Storms.

Rank	Country	City	2005 Assets at Risk	2070 Estimated Assets at Risk
			(Billions, U.S. dollars)	(Billions, U.S. dollars)
1	United States	Miami	416.29	3,513.04
2	China	Guangzhou Guangdong	84.17	3,357.72
3	United States	New York–Newark	320.2	2,147.35
4	India	Kolkata (Calcutta)	31.99	1,961.44
5	China	Shanghai	72.86	1,771.17
6	India	Mumbai (Bombay)	46.2	1,598.05
7	China	Tianjin	29.62	1,231.48
8	Japan	Tokyo	174.29	1,207.07
9	China	Hong Kong	35.94	1,163.89
10	Thailand	Bangkok	38.72	1,117.54
11	China	Ningbo	9.26	1,073.93
12	United States	New Orleans	233.69	1,013.45
13	Japan	Osaka-Kobe	215.62	968.96
14	Netherlands	Amsterdam	128.33	843.7
15	Netherlands	Rotterdam	114.89	825.68
16	Vietnam	Ho Chi Minh City	26.86	652.82
17	Japan	Nagoya	109.22	623.42
18	China	Qingdao	2.72	601.59
19	United States	Virginia Beach	84.64	581.69
20	Egypt	Alexandria	28.46	563.28

Source: Nicholls et al. 2008.

USAID delivers both foreign humanitarian and development assistance. USDA provides non-emergency food-assistance programs to help meet recipients' nutritional needs and support agricultural development and education. Each of these assistance programs, combined with trade capacity–building efforts, support long-term economic development and can help countries transition from food-assistance recipients to commercial buyers. Programs focus on the world's poor, particularly those living in rural areas and dependent on agriculture for their livelihoods. These programs and initiatives address the nexus of climate change and global food security, and have implications for U.S. food systems. They include alternative livelihoods programs; the Food for Peace development food-assistance programs authorized primarily by the Agricultural Act; the U.S. government's Global Climate Change Initiative; and the U.S. government's flagship global hunger and food security initiative Feed the Future.

Feed the Future seeks to reduce poverty and improve nutrition through agriculture-led growth and incorporates several cross-cutting themes, including nutrition, gender, and climate change. Feed the Future addresses climate resilience to achieve higher productivity and incomes, adapt to climate change, and mitigate GHG emissions, where appropriate. Feed the Future programs create new opportunities for the most-vulnerable households through various program goals, including agricultural and nonagricultural development; maternal and child health and nutrition activities; promotion of water, sanitation and hygiene; infrastructure development; and rehabilitation of the natural resource base.

Such programs can help increase food security and improve maternal and child health. Programmatic assessment indicates that Feed the Future and other U.S. government–led efforts have contributed to reductions in poverty and child stunting in the areas of Bangladesh where Feed the Future operates, a 9% reduction in stunting in Ethiopia over the most recent 3-year evaluation period, a 33% reduction in stunting in Ghana, and a 55% increase in the average Honduran income between 2012 and 2014, which elevated 36,000 above the 1.25 USD per person per day poverty threshold (Feed the Future 2015 Progress Report). The 5-year USAID-funded development food assistance program (through Food for Peace) Shouhardo II implemented a number of agricultural and maternal and child health activities in Bangladesh from 2010–2015, and demonstrated a significant increase in the number of months of adequate household food provisioning, from 5.9% at the start of the program to 11% in the final evaluation, and an 81% increase in the average household dietary diversity, an indication of household socioeconomic status in the target area. In addition, the program saw a significant decrease in stunting of nearly 21% in children 6–59 months (from 61.7% to 48.8%) and a significant increase in the percentage of women receiving antenatal care, from 47.1% to 85.3% (TANGO 2015). In another example, the WALA program produced a significant reduction in stunting of 12.5% in Malawi among children 6–59 months from the start of the program to final evaluation and an increase in the proportion of deliveries attended by a skilled health professional, from 78% to 88.5%, in target areas. In addition, the WALA program enabled an increase in the modified household incomes of 14% between the start of the program and final evaluation, and a decrease in the proportion of households that reported losses of livelihood assets due to shocks and stresses, from 7.8% to 6.8% (CRS 2014). Finally, USAID funds the Famine Early Warning System Network (FEWS NET). Every 3 months, FEWS NET analysts conduct scenario-building exercises to estimate food security outcomes for the coming 6 months. The situation in areas of concern is assessed and assumptions are made about the future in order to consider how those assumptions might affect food and income for poor households. Then, the most likely scenario is determined and the expected level of food insecurity is classified. Finally, major events or changes that could affect the outcome, including climate-related events, are identified to inform decision makers and contribute to emergency response planning. FEWS NET has used scenario building to assess the impact of drought on poor farming households in Somalia and project the impact of extensive flooding in Nigeria on the regional market (Husak et al. 2013).

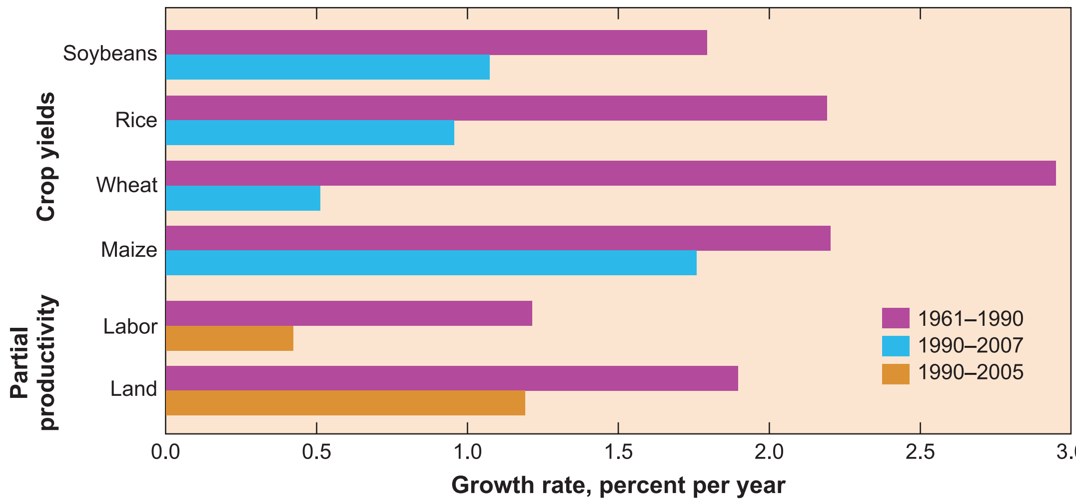


Figure 8.3 Global agricultural yield and productivity growth rates, 1961–2007. *Yield is measured as metric tons per hectare. Labor and land productivity are total agricultural output per agricultural worker and agricultural area, respectively, excluding China. Total agricultural output was derived using 1999–2001 price weights. Source: Alston et al. 2009.*

8.3.3 Technology and Information Assistance

The United States has been a world leader in the development of new technologies that have greatly increased the quantity and quality of food over the past 100 years (Mowery and Rosenberg 1998 p. 6). Organized public and private investment in agricultural research has been a major contributor to the rapid growth in agricultural productivity experienced since the 1950s (Evenson et al. 1979). Wang et al. (2013) find a strong direct relationship between public investment in agricultural R&D and total factor productivity (TFP). Fuglie and Rada (2013) argue that changes in TFP are a robust measure of the effect of new agricultural technologies, an indication of the rate at which basic research is translated into practical applications. TFP has been rising in many developing countries (Ray et al. 2012). In many regions, crop yields and TFP have remained low; it is possible this may be the result of little agricultural research and investment.

Alston et al. (2009) observe that in the past, most countries (especially low-income countries) have relied heavily on knowledge and technology resulting from agricultural research by a small number of developed countries, including the United States. Some such technologies include crop breeding that increased crop tolerance to drought, heat, and salinity, as well as early maturation breeds that shorten the growing season and reduce farmers' exposure to risk of extreme weather events (Lybbert and Sumner 2012). Such technologies are expected to provide critical climate-change adaptation possibilities for developing countries. Looking into the future, technology will need to play a large role in helping farmers everywhere increase the productivity of their operations, especially in the face of challenging climate changes. However, current productivity trends are not promising. Alston et al. (2009) note a global slowdown in the growth rates of wheat, rice, maize, and soybean yields over the period 1990–2007 versus the period 1960–1990. They postulate that declining investment in agricultural research and development globally, but especially in high-income countries like the United States, is a primary driver of lower yield growth. There has been a global commitment to increase investments in agricultural development, hunger, and undernutrition, which may result in an increased

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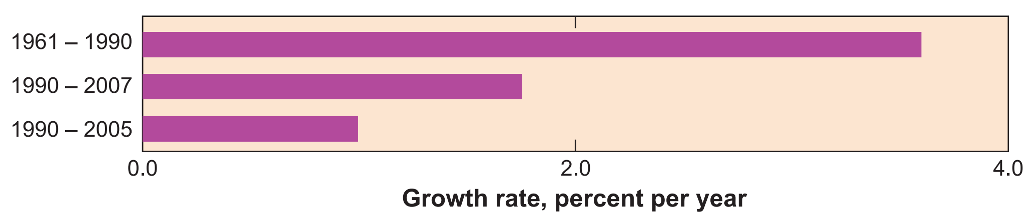

Figure 8.4 Annual growth rate of U.S. public agricultural R&D spending, 1950–2007. *The underlying public agricultural R&D spending data are adjusted to reflect 2000 prices. Public agricultural R&D includes intramural USDA research and research conducted at the state agricultural experiment stations. Source: Alston et al. 2009.*

rate of yield growth (Flora 2010). Figures 8.3 and 8.4 demonstrate a relatively close correspondence in growth rates between U.S. public investment in agricultural research and development and global crop yield and productivity growth over the period of 1950–2007. While increasing private-sector research has compensated for some of the loss of public investment in agricultural research and development to some extent, public divestment comes at a time when concerns about stagnating yields for major crops such as rice, maize, and soybeans have been raised (Cassman et al. 2003).

Conventional breeding approaches to increasing climate resilience in crops will be important in the future (Tester and Langridge 2010). Especially important are the development of new technologies that improve genotyping and phenotyping methods and the expansion of available genetic diversity in breeding germplasm. The biggest opportunity to improve food security with those technologies is to deliver them to developing countries in a form that is economically accessible and readily disseminated (Tester and Langridge 2010). Recent experiences with the development and use of GM crops such as maize and soybeans in the United States illustrate the potential for GM crops to increase yields in other areas (Xu et al. 2013). There is insufficient evidence to assess the degree to which GM crops can potentially contribute to overall global food security in the future, but it does appear that genetic engineering, along with conventional breeding approaches, have the technical potential to play a significant role in expanding global agricultural capacity.

As agriculture becomes increasingly science-based, the role of information in helping farmers deal with risk, particularly weather and climate risk, has increased. Improving climate risk management throughout the food chain will be an important strategy for adapting to climate change. The United States has been a leader in the development and application of Agricultural Decision Support Systems (ADSS) that help farmers manage risk, including climatic changes (Agrios 2005). The ADSS are computer simulation models, sometimes coupled with advanced observational technologies, that can be used by individual producers or distributors to help make decisions under uncertainty. In addition to modeling climatic uncertainty directly, these systems have also been developed to determine optimal responses for pest-management and irrigation considerations. These systems represent another U.S. technology that is easily transferable and helps to improve agricultural efficiency in both the developed and developing world when facing climatic uncertainty.

Once new technologies are developed, whether they are new cultivars or GM crops, new water- and soil-management strategies and other agronomic practices, or changes in crop species planted, such technologies must be proactively managed and directed toward targeted regions and situations in low-income countries (Lybbert and Sumner 2012). For example, new cultivars must be adapted to local conditions and distributed to farmers through a system of poorly connected institutions and markets. Lybbert and Sumner (2012) point out that inefficient input markets in many developing countries, including little private-sector investment and involvement in the seed sector, can severely limit farmers' access to new varieties. The United States, therefore, has an opportunity to proactively engage with regions being targeted for technology transfer aimed at facilitating agricultural adaptation to climate change.

The recent emergence of "Climate-Smart Agriculture" (CSA; FAO 2014a), which intends to simultaneously increase productivity, conserve natural resources, and adapt to changing climate patterns, is one example of an organized movement to engage governments to expedite and focus adaptation to climate change. The FAO (2014a) states that "CSA integrates the three dimensions of sustainable development (economic, social, and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars: (1) sustainably increasing agricultural productivity and incomes; (2) adapting and building resilience to climate change; and (3) reducing and/or removing GHG emissions, where possible." Rather than a set of prescribed technologies or policies, CSA is a conceptual framework that encourages governments and other food-related institutions to take an organized approach to preparing food systems to cope with climate change.

CSA has four operational goals (Lipper et al. 2014). First, CSA seeks to build an evidence-based catalog of adaptation options that are shown to be effective in certain situations and locations (Lipper et al. 2014). Second, it focuses on improving institutional efficiency in disseminating adaptive strategies. Four main areas that require public support to complement private efforts in that regard are identified: "(1) extension and information dissemination, particularly on using evidence to adapt practices to local conditions; (2) coordinated efforts where practices generate positive spillover benefits, for instance by reducing flood risks or pest outbreaks, or preserving biodiversity; (3) comprehensive risk-management strategies for managing extreme weather events that affect many farmers simultaneously; and (4) reliable, timely and equitable access to inputs to support resource-use efficiency" (Lipper et al. 2014). Third, CSA aims to improve coordination between national agricultural, climate change/environmental, and food system policies. Fourthly, CSA seeks to improve the targeting of financing to support the transition to CSA. In particular, the linkage of climate-related financing (e.g., Global Environment Fund and others) with traditional sources of agricultural financing is an important part of these efforts.

8.4 Domestic Changes Resulting From Global Changes

Given changes in the expectations of U.S. producers, then, to participate in the world market, changes in transportation infrastructure for moving food from its place of origin to its ultimate consumer can be decisive. For example, given a globally averaged 0.61 m rise in sea level—roughly that which might be expected under RCPs 6.0 or 8.5 (Church et al. 2013)—Kafalenos et al. (2008) predict that 64% of the U.S. Gulf Coast region's port facilities may be inundated, while an additional 20% of highway arterial miles and 19% of total interstate miles would be at risk by 2100. A 1.22 m sea level rise, which exceeds current RCP 8.5 estimates (Church et al. 2013), would likely inundate nearly three-quarters of Gulf-region port facilities; 28% of highway arterial miles and 24% of interstate miles would also be at risk. The study also found that storm surge could significantly affect rail transport, though sea-level rise alone was a lesser concern for that mode of food shipment. A 5.5 m storm surge would place one-third of the rail lines in the region at risk, while a 7 m storm surge would place 41% of rail lines and 51% of freight facilities in the region at risk by 2100, challenging the transportation system's capacity for the timely export of food.

Watersheds supplying water to the Great Lakes are likely to experience drier conditions in a changing climate, resulting in lower water levels (Angel and Kunkel 2010, Chao 1999, Easterling and Karl 2001). This projected decline in the Great Lakes water level potentially reduces shipping capacity and increases the cost of shipping agricultural and other commodities via this artery (Millerd 2005, 2011). Using scenarios that were roughly comparable to the RCPs 4.5 and 8.5 discussed in this report, Millerd (2011) projected an increase in the operating costs of U.S. vessels exporting agricultural products of between 4.15% and 22.62%. Using sensitivity analysis of 5%, 10%, and 20% increases in waterborne shipping costs, corresponding to Millerd's 2011 projections along the Great Lakes, Attavanich et al. (2013) predicted reduced grain shipments to and from Great Lakes ports ranging from 4% to 92% under scenarios comparable to RCPs 4.5 and 8.5, respectively. At the same time, all scenarios reflect higher grain shipments to Lower Mississippi River ports (up to 3%) and to Atlantic ports (up to 49%).

U.S. producers are sensitive to changes in the global market and are likely to respond as the geography of agriculture adjusts to new climatic circumstances.

U.S. agricultural producers respond to changing global market conditions by altering what they grow or other elements of their operations. Changes in climate are one source of change. As consumptive demands expand and ideal production zones shift, alterations to the global food supply and demand equation are likely to occur, making some foods more profitable and others less so. U.S. producers are sensitive to changes in the global market and are likely to respond as the geography of agriculture adjusts to new climatic circumstances.

8.5 Conclusions

The U.S. food system is part of a larger global food system that produces, processes, stores, transports, sells, and consumes food through an international

network of markets. One outcome of effective food systems, regardless of scale, is food security (Ingram et al. 2013). Climate change will challenge that outcome in many geographic regions across the Earth. This chapter addressed two major questions: (1) In what ways is the U.S. food system likely to affect food security in other countries, especially those at risk of food insecurity, as climates change? And (2), how might the effects of climate change on global food security affect the U.S. food system? These are daunting questions and the research literature does not contain fully developed answers. But useful insights can be deduced from the foregoing review.

Answers to these questions are conditioned in part by how climate change is likely to affect the U.S. food system. Climate change has been ubiquitous across the United States over the past century. All parts of the country except the Southeast have warmed, and precipitation intensity has increased nearly everywhere in the country. There are important regional variations in precipitation amounts. For the future, all of the United States is projected to warm considerably, regardless of the path of future GHG emissions. Much of the Corn Belt is expected to receive less summer precipitation, although most of the country is projected to receive higher winter precipitation. Such climate changes are likely to have important effects on U.S. agricultural production. While production across most of the United States should be able to accommodate the initial stages of climate change without major yield loss by implementing simple agronomic adjustments such as changes in irrigation timing and amounts and cultivar choices, as climate change continues, crop yields, livestock production, and revenues are expected to decline. Decline estimates are likely to be on the low end because of less-well-known indirect climate effects on factors such as pests and pathogens, which are currently excluded from yield- and livestock-loss modeling and estimates.

The United States has an important role to play in helping less economically advanced regions, many of which are currently food insecure, manage the consequences of climate change for their food security. The United States is the largest food exporter in the world, although its market share is shrinking as other nations increase exports. Import demand in many developing countries is expected to rise, thus creating additional export markets for the United States. Some simulations, such as the AgMIP work cited in this report, estimate that climate change will increase U.S. food imports by up to 5% over 2005 levels by 2030; the same simulations suggest slightly smaller increases in exports.

Many developing countries are becoming food exporters (e.g., Brazil), and high-value crops including coffee and fresh produce are being purchased by the United States. Such purchasing influence over development may help to cope with climate change. An important facet of U.S. trade for climate-change adaptation is the export of virtual water from the United States, which may provide a channel for the trade of water-intensive foods to countries experiencing drier conditions.

U.S. international food- and development-assistance programs are likely to continue to provide strategic assistance for both long-term agricultural development and for emergency conditions in food-insecure regions. Such programs have been reconfigured in recent years to complement multiple development objectives, including promoting climate-adaptation strategies and improving long-term efficacy.

The United States has been influential in developing and disseminating new technologies designed to help farmers worldwide cope with climate change. The United States has been a major source of innovations that have helped increase agricultural productivity, not just for U.S. producers, but for producers in other countries, too. Investment in agricultural research and development is important to improving yields. Many tools exist or may be developed to maintain or improve robust food systems under climate change, including agronomic and conventional crop-breeding adjustments, GM crops, and sophisticated computerized decision-making tools for managing risk. Climate Smart Agriculture is among the first organized efforts to encourage investment in adapting food systems to climate change by integrating sustainable development goals with locally tailored adaptation strategies. CSA is gaining momentum in the research, translational, and popular literature.

As climate-change effects on global food security become more pronounced, there are likely to be important consequences for the United States. food system. The U.S. is expected to see the rate of growth in food exports decline with climate change, while the rate of food imports is expected to grow relative to exports, thus changing the U.S. balance of food trade. An important component of successful international trade is the existence of adequate infrastructure (e.g., roads and ports) to effectively handle exports and imports. Ports, riverine barge systems, and roads in regions experiencing sea-level rise and changing frequency of climate extremes such as heat waves and drought due to climate change may literally impede the movement of food from places that produce food to places that cannot.

In summary, the U.S. food system is likely to experience effects from climate change, including yield loss in important production regions, stress on important agricultural resources such as water and soil, and disruption to transportation infrastructure. However, evidence suggests that the United States will continue to maintain a strong position as a major food exporter and importer. The United States has the opportunity to maintain a leadership position in developing new strategies and technologies for adapting food systems in food-insecure regions in a changing climate.


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